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A PRELIMINARY ANALYSIS OF RISK RATINGS USED IN APPRAISING BARK BEETLE SUSCEPTIBILITY OF PONDEROSA AND JEFFREY PINES

by

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INTRODUCTION

Investigative work on the habits of bark beetles infesting stands of commercial ponderosa and Jeffrey pine has indicated that certain types of trees are generally selected by the beetles during attack. This selection, particularly by the western pine beetle in ponderosa pine, has stimulated the belief for many years that the removal from the stand of the trees most preferred by the attacking beetles would do more to reduce and check recurring timber loss than action directed only toward a destruction of beetle populations. Studies carried on during recent years to test this belief have had as their principal objective the reliable determination of classes or types of trees most often selected in attack. When these trees could be accurately rated according to their relative risk, the most important obstacle toward the solution of the problem of forest insect control through forest management practices would then be overcome.

STUDIES OF TREE SUSCEPTIBILITY

In the first investigation of insect damage to the ponderosa pine stands of the west, Hopkins (4) noted that many of the trees which were being attacked and killed by bark beetles were large, overmature and generally the most valuable in the stand. In this investigation, it was noted that these large, overmature trees seemed to be attacked more frequently than the other smaller and immature trees. In later years other investigators began detailed studies of the types of trees which were being selected by the beetles in order that selective cuttings of only susceptible trees could be tested as indirect measures for control.

In 1928 Person (5) advanced the theory of tree selection by the western pine beetle and showed that trees of slow annual growth were most often selected by the beetles. Keen in 1936 (2) proposed a susceptibility classification for ponderosa pine based on the factors of tree age and crown vigor. This study showed that trees in mature and overmature age groups and of poor crown vigor were most susceptible to bark beetles. In a revision of this work in 1943 (3) crown size and vigor were given more emphasis than position in determining tree class. In his revision Keen showed that any tree, regardless of class, may currently vary in risk from the average susceptibility of the class as a whole.

RATINGS OF RISK

In 1936 a trial system was devised whereby the current health of a tree could be evaluated by the extent of decadence in crown regardless of the tree's age, dominance or crown size. The relative degree of tree risk to bark beetle attack was then judged from this appraisal of current tree health. In this system of judging current tree health and relative risk, crown vigor alone, as indicated by length and number of needles, presence of dead or dying twigs and branches, needle color, top-killing or other symptoms of partial but incomplete insect infestations, was used as a base for appraisals.

The studies of beetle risk in individual trees have been continued on sample plots throughout the pine stands of northeastern California since 1936. From these plot records it has been found that most of the trees which are attacked and killed can be accurately appraised several years in advance of death. However, there was doubt as to whether the accuracy in predicting future loss by appraising risk for individual trees could be extended for sufficient time to make partial cuttings of only high risk trees practicable for control purposes. The trees most liable to attack by the beetles were evidenced by the decadent condition of the crowns. Since the crowns in other green trees often showed varying conditions of vigor and decadence, or current health, it seems a possibility that a relative expectancy to attack by beetles might be made for all trees in the green stand. Gradually, as ideas concerning risk were developed, a classification was devised whereby trees were grouped into four risk classes, representing a relative measure of susceptibility to attack (6). The most healthy and vigorous trees in the stand were rated as low risk (Risk 1); whereas the most unhealthy trees, those showing declining vigor and thoroughly decadent crowns, were rated as very high risk (Risk 4). Trees showing intermediate conditions of crown decadence, or current health, were likewise grouped into classes of moderate risk (Risk 2) and high risk (Risk 3).

Though the risk classes were tentative, they were considered as applicable to both ponderosa and Jeffrey pine throughout the stands of commercial pine timber east of the Sierra Nevada-Cascade Mountain Range in northeastern California. Before their validity could be definitely established, it was necessary to determine whether (1) the ratios of mortality between the four classes were significant; (2) the expected occurrence of loss in each class would remain valid and stable for extended periods of time; (3) the expected and predicted occurrence of loss were accurate for both pine species and (4) in what ways characters other than those of crown conditions might affect susceptibility and mortality. The accumulation of loss records on the study areas now makes it possible to make preliminary analyses of these points.

RATE OF LOSS BY RISK CLASSES

In some sample areas, risk-rated trees have been studied since 1936. The period of study is shorter on other plots. Tree mortality thus far recorded on all plots has amounted to 557,300 board feet during a period of from one to six years after risk rating. Of this total, 13 percent was Jeffrey pine. This record, particularly for ponderosa pine, is considered as sufficient to establish a reliable ratio of mortality for each risk class; to show how time affects the occurrence of loss in each risk class; and to determine in a preliminary way how age, crown vigor (Keen's Tree Class (2) and tree position (Dunning's Tree Class (1) affect the ratio of mortality for the four risk classes.

At the time each plot was established for study, all ponderosa and Jeffrey pines over 12 inches d.b.h. were measured, classed by Dunning's and Keen's systems, and rated into one of the four risk classes. At yearly intervals each plot has been re-examined and a record made of all insect-killed trees. Thus far, in ponderosa pine, a total of 404 trees with 484,600 board feet have been found killed by beetles; and 54 Jeffrey pines with 72,678 board feet also have been killed. The distribution of green and beetle-killed trees in each risk class is given in Table 1 for both tree species. The ratio of mortality tabulated on a board foot volume basis is indicative of the relative rate of loss in the four classes of risk. It is obtained by dividing the percent occurrence of the volume of insect-caused loss in any one risk class by the percent occurrence of the volume of the same risk class found in the green stand. Ratios above 1.00 indicate high risk, or preference in attack; those below 1.00 indicate low risk, or a lack of selection.

Table 1. Distribution, by risk classes, of green and beetle-killed trees on sample plots.

(PONDEROSA PINE)

	GREEN STAND				INSECT-CAUSED LOSS			
Risk Class	Total No. of trees	% Total trees	Total Volume M b.m.	% Total M b.m.	Total No. of trees	Total Volume b.m.	% Total Loss	Mortality Ratio
1	17,254	66.7	12,176	54.4	34	25,380	5.2	0.1
2	5,624	21.8	6,531	29.2	52	51,006	10.5	0.4
3	1,614	6.2	2,001	8.9	65	81,598	16.8	1.9
4	1,368	5.3	1,668	7.5	253	326,651	67.5	9.0
Total	25,860	100.0	22,376	100.0	404	484,635	100.0	
Average								1.0

(JEFFREY PINE)

	GREEN STAND				INSECT-CAUSED LOSS			
Risk Class	Total No. of trees	% Total trees	Total Volume M b.m.	% Total M b.m.	Total No. of trees	Total Volume b.m.	% Total Loss	Mortality Ratio
1	1,732	74.5	1,296	61.4	3	2,593	3.6	0.1
2	412	17.7	570	27.0	11	15,789	21.7	0.8
3	94	4.1	127	6.0	8	12,141	16.7	2.8
4	86	3.7	118	5.6	32	42,155	58.0	10.4
Total	2,324	100.0	2,111	100.0	54	72,678	100.0	
Average								1.0

From Table 1 it will be noted that approximately 17 percent of the green ponderosa pine volume occurs in risk groups 3 and 4 (high risk) and 83 percent in groups 1 and 2 (low risk). Of the beetle-killed trees, the reverse is true; 84 percent of the loss occurred in high risk trees and

16 percent in low risk. The ratio of mortality for each risk group indicates that trees in groups 3 and 4 are susceptible, whereas those in groups 1 and 2 are more resistant.

In Jeffrey pine, the distribution by risk of both green and beetle-killed trees differs slightly from ponderosa pine. A smaller percentage of the green stand and the insect loss occurred in the groups of high risk. However, this record indicates that loss predictions for Jeffrey pine in the areas studied can be made with sufficient accuracy to justify appraising these trees for selective cutting in indirect control measures.

By comparing the percent of risk classes killed during each year for the period of record, it was found that the rate of loss in each risk class varied only slightly during each of the six years for both ponderosa and Jeffrey pine (Table 2). Seasonal differences in the percentage of trees killed in each risk class were found to be related directly to fluctuations in the general trend of infestations, and were not an indication of a lack of stability in ratings during the period studied.

Table 2. Percentage of trees killed annually on sample plots, by risk classes, following classification.

Period following marking	PONDEROSA PINE					JEFFREY PINE				
	Risk 1	Risk 2	Risk 3	Risk 4	Total stand	Risk 1	Risk 2	Risk 3	Risk 4	Total stand
1st year	.02	.23	1.13	8.08	.78	.00	.04	.61	16.41	.96
2d year	.09	.21	.87	4.29	.51	.00	.92	1.15	7.94	.76
3d year	.06	.18	1.28	4.90	.56	.19	1.29	2.97	6.27	.99
4th year	.01	.14	.31	1.15	.16	.00	.26	1.35	3.90	.37
5th year	.04	.01	.41	.91	.13	.01	.27	1.15	1.24	.22
6th year	.00	.00	.09	.26	.03	.00	.00	2.32	.00	.14
Total	.21	.78	4.08	19.59	2.17	.20	2.77	9.56	35.77	3.44

By comparing the percentage of the total stand which has been killed each year to the occurrence of loss in each risk class during corresponding periods, it will be noted that the rate of loss in any year subsequent to risk rating corresponds closely to the ratios of mortality given in Table 1. Table 2 also shows that in ponderosa pine, 19.6 percent of the Risk 4, and 4.1 percent of the Risk 3 trees, have been killed during six years, whereas only 1.0 percent of the Risk 1 and 2 trees were killed. During the same period, the rate of loss in high risk Jeffrey pines was nearly twice as great as that for ponderosa pine, amounting to 35.8 percent of the Risk 4 and 9.6 percent of the Risk 3 trees.

Thus far, the records of loss from the study areas in northeastern California indicate that ratings of risk are applicable to both ponderosa and Jeffrey pines under yearly infestation conditions where up to 1.00 percent of the green stand is killed, and are stable and valid for at least six years. Since losses were at a low level during these studies it is not known what effect, if any, epidemic conditions would have upon the mortality ratios of the risk classes. It is to be expected, however, that the beetles would exhibit less preference for Risk 3 and 4 trees and more for Risk 1 and 2 trees during epidemic periods.

CONSIDERATION OF OTHER CHARACTERS

The primary objective of this study of tree risk was to determine what characters could best be used to denote trees most likely to be attacked and killed by bark beetles. In the studies so far, it has been found that approximately 84 percent of the total loss in ponderosa pine can be appraised as high risk (Risk 3 and 4) prior to infestation and death by using only deteriorated crowns in risk appraisals. To increase the accuracy in picking out which trees are most likely to become attacked, in order to provide for the increased effectiveness of control through selective cutting, it is necessary to (1) weed out the non-important from the significant crown characters indicating current health, or (2) to determine what other characters beside those of deteriorated crowns also indicate the beetle susceptibility of trees. A determination of the reliability and significance of crown characters indicating risk cannot be completed until additional records of loss are obtained from trees in which all conditions of crown have been recorded prior to the time each tree became infested. An analysis can be made, however, of the ways in which conditions other than those used in rating tree risk might indicate susceptibility and mortality.

MATURITY AS A FACTOR IN SUSCEPTIBILITY

On nearly all of the sample areas where ratings of risk have been marked on each tree, some loss has occurred in groups which had not been appraised as high risk prior to death. Of all the trees which were killed in the low risk groups (Risk 1 and 2), a majority were mature and overmature. In general advanced age in trees should indicate a lowered vigor and declining health. Because of the overmature age of most trees which were killed in both low and high risk classes, it was thought that age might be an important added character to decadent crowns for use in determining high risk and susceptibility. If age, as an independent, was contributing to current poor vigor and high risk in trees, a comparison of ages of trees in the green stand to those found infested by beetles should indicate what part maturity plays in tree susceptibility. Since all trees on the study plots were classed into Keen's "physiological age groups" of young (0-80 years), immature (80-180 years), mature (180-300 years) and overmature (over 300 years) as each plot was established and all trees which have since become infested and killed were similarly classed, it is possible to make comparisons of mortality by age and risk. This comparison by volume, b.m., is given in Table 3.

Table 3. Comparison of tree mortality by age and risk groups.
(PONDEROSA PINE)

Risk Groups	Age Groups 1 0-80 yrs.	2 80-180 yrs.	3 180-300 yrs.	4 Over 300 yrs.	Total
1	0.05	0.02	0.05	0.15	0.09
2	-	0.15	0.23	0.40	0.35
3	-	-	1.78	2.04	1.98
4	-	3.00	5.85	9.77	9.00
Total	0.05	0.06	0.42	1.40	1.00

From the record of mortality given in Table 3 it is evident that risk does increase with age, but age does not become an important factor until overmaturity is reached. As indicated in the table, age does not overshadow or outweigh the importance of risk characters as an indicator of susceptibility. Risk 4 trees are of highest susceptibility in all age groups, then Risk 3 trees in Age Groups 4 and 3. All other trees are relatively non-susceptible. It may be concluded therefore that tree age, especially overmaturity, should be considered as a supplementary character to the condition of crowns in rating of risk.

CROWN VIGOR AS A FACTOR IN SUSCEPTIBILITY

In addition to the factors of crown decadence or current tree health used in rating tree risk, there are the other crown factors of general vigor as indicated by size of crown, abundance of foliage and tree position which were used by Keen in the original definition of his crown "vigor groups." Since some of the considerations are common to both classification, it might be expected that the mortality rates for these two classifications would be nearly parallel. This relationship is shown in Table 4, using the data from plots in northeastern California.

Table 4. Comparison of mortality ratios by crown vigor and risk classes. (PONDEROSA PINE)

Risk classes	Crown vigor classes* A	B	C	D	Total
1	0.1	0.1	0.1	0.4	0.1
2	0.3	0.4	0.4	1.1	0.4
3	1.9	2.1	1.9	2.2	2.0
4	4.7	11.6	8.1	16.7	9.0
Total	0.3	1.1	2.3	1.6	1.0

* It should be noted, however, that the classification of these trees into Keen classes was done in 1936 and was according to the early definition of crown vigor classes which stressed tree position, and not according to the "redefinition of 1943" which laid greater emphases on crown size, density and general vigor.

Table 4 indicates that subdividing trees according to the risk groups is of much greater significance in determining probability of death than subdividing according to crown vigor classes (based primarily on size and position of crowns). Risk 4 trees are by far the most susceptible element in the stand. Once these are removed there is little choice between Risk 3 trees whether of A, B, C or D crowns. With the exception of "D crowns," no crown classes of Risk 1 or 2 group showed any tendency towards susceptibility.

The data analyzed in this study are based on 404 risk rated and classified ponderosa pine and 54 Jeffrey pines killed on 29 check plots in northeastern California during a period of five years. Most of these plots were on Black's Mountain Experimental Forest. The data show that under these conditions most of the loss occurred in trees of highest risk. It can be concluded that deteriorated crown characters indicative of poor health furnish reliable criteria for predicting future loss over a short period of time (extent of record - 6 years) and under the endemic loss conditions which prevailed on the subregion between 1937 and 1943.

Further subdividing risk classes by age showed that the preponderance of loss had occurred in overmature trees of Keen's class 4, with younger trees definitely less susceptible. No additional improvement in selection of susceptible trees was gained by subdividing risk by Keen's crown vigor classes.

COMPARISON OF MORTALITIES BETWEEN RISK AND KEEN'S TREE CLASSES

In his classification of the relative susceptibility of ponderosa pine to bark beetle attack, Keen (2) has shown the rates of mortality which may be expected in each of the 16 classes over comparatively long periods of time. The four classes of risk, which are appraisals of current health in trees, are indicative of relative susceptibility of but the next few years. It should be expected, therefore, that most of the trees which currently become infested would be of high risk in the classes of highest susceptibility as determined by Keen.

Given in Table 5 are the ratios of mortality (on a tree basis) obtained by Keen (3) from 51,409 trees killed on 112,409 acres of sample plots during 1928-31, 1935-37, 1939-40 in eastern Oregon and Washington and northeastern California; and the ratios (on a volume basis) as determined from the much smaller record of loss in the study of risk since 1936 in northeastern California.

Table 5. Ratio of mortality for Keen's tree classes.

Age Classes	CROWN CLASSES								Total	
	A		B		C		D			
1	0.1	0.0*	0.3	0.1*	0.8	0.0*	1.1	0.0*		0.0*
2	0.2	0.0	0.6	0.2	1.0	0.1	1.5	0.0		0.1
3	0.3	0.1	1.0	0.6	1.9	1.1	2.6	0.5		0.4
4	0.4	0.5	1.4	1.4	2.7	2.6	3.8	4.4		1.4
Total		0.3		1.1		2.3		1.6	1.0	1.0

*Data on a volume basis from study of risk in northeastern California.

The variation in mortalities between the two sets of data are believed to be due to the difference in the interpretation of Keen's classes in the two regions; in conditions of stands in the areas where each study was conducted; and the smaller amount of data in the more recent study in northeastern California. Both sets of data show, however, that susceptibility to attack is highest in classes 4D, 4C, 4B and 3C.

By segregating the occurrence of loss in Keen's 16 classes into each of the four classes of risk, Table 6, it is found that the higher mortality rates are found in the high risk groups and to a considerable extent in Keen's most susceptible classes, as expected.

Table 6. Ratio of mortality by risk group and Keen's tree classes. (PONDEROSA PINE)

Risk Groups	Keen Age	Keen Vigor A	B	C	D	Total
1	1	0.0	0.1	0.0	0.0	0.03
	2	0.0	0.1	0.0	0.0	0.01
	3	0.0	0.1	0.2	0.1	0.05
	4	0.1	0.2	0.1	1.1	0.15
	Total	0.1	0.1	0.1	0.4	0.09
2	1	0.0	0.0	0.0	-	0.00
	2	0.0	0.5	0.0	0.0	0.19
	3	0.2	0.2	0.3	0.6	0.23
	4	0.4	0.5	0.4	3.6	0.44
	Total	0.3	0.4	0.4	1.1	0.39
3	1	0.0	0.0	0.0	-	0.00
	2	0.0	0.0	0.0	0.0	0.00
	3	1.4	2.1	1.4	1.0	1.75
	4	2.2	2.1	2.0	8.0	2.18
	Total	1.9	2.1	1.9	2.2	2.02
4	1	-	0.0	-	-	0.00
	2	6.0	10.0	1.5	0.0	5.80
	3	3.2	6.8	6.1	5.7	5.67
	4	5.5	13.2	8.3	27.7	9.78
	Total	4.7	11.6	8.1	16.7	9.00
ALL TOTAL		0.3	1.1	2.3	1.6	1.00

Table 6 also shows, however, that trees in Keen's less susceptible classes are sometimes attacked and killed when they are currently of high risk; likewise, many of the trees which are included in the susceptible classes by Keen are found to be of low current risk. It can be concluded from Table 6 that deteriorated crown characters as used for indicating current poor health in trees are the best criteria for predicting future loss, at least for short periods of time, (extent of record - 6 years).

That high risk trees are predominately those in the overmature age groups (age 4) and in the B and C crown vigor classes is indicated by an examination of the distribution of risk volume found in the green stand on plots in northeastern California (Table 7).

Table 7. Percent of risk volume (Risk 3 and 4) in green stand. (PONDEROSA PINE)

Keen's Age groups	Crown vigor classes A	B	C	D	Total
1	0.00	0.00	0.00	-	0.00
2	0.03	0.05	0.03	0.01	0.12
3	0.65	1.36	0.64	0.06	2.71
4	1.50	5.90	5.96	0.04	13.40
Total	2.18	7.31	6.63	0.11	16.23 percent

Table 7 shows that in these stands with a total of 16.23 percent of the volume in high risk trees, 82.5 percent of this volume was found in the overmature age class 4 and 73 percent of it in two classes; i.e. 4B and 4C. Only 17 percent of risk volume was found in mature trees of age Class 3 and a negligible amount in immature classes 1 and 2.

By comparing the ratios of mortalities in Tables 5 and 6 it will be noted that, with the exception of risk class 4 and the overmature trees in risk 3, the rate of loss in Keen's most susceptible classes (data from study of risk in northeastern California) are higher than those of all other risk groups. In application, this would indicate that when it is found necessary to select trees for cutting to increase the volume to be removed in sanitation-salvage treatments, it would be advisable to include all trees not currently of high risk in Keen's most susceptible classes.

SUMMARY

During 1936 and 1937 studies of the susceptibility of individual trees to attack by bark beetles led to the development of a system whereby green trees were grouped into four classes denoting current risk to bark beetle attack. The risk classes were developed as a means of employing a method of indirect bark beetle control which would remove from the stand, by a selective cutting, the trees most subject to attack. The risk values were tentative pending the occurrence of sufficient loss on study areas to determine whether (1) mortality ratios between classes of risk were significant, (2) risk ratings were applicable to both ponderosa and Jeffrey pine, (3) expected loss could be determined for extended periods of time and (4) in what ways characters other than deteriorated crowns might affect susceptibility and mortality.

Ratios of mortality for each risk group have been determined from 557,300 board feet in trees that have been killed during periods of from one to six years following the ratings of risk that were applied on all trees as sample plots were set up for study. By comparing the percent of risk classes killed each year, and for the entire period of record, with the percent of occurrence of the green stand by risk, it has been found that mortality ratios for each risk class are significant.

This comparison also showed that the ratings of risk are applicable to both ponderosa and Jeffrey pine under infestation conditions ranging from 0.03 - 0.99 percent of the green stand and can be used in predicting future loss for at least six years.

By comparing the ages of trees found infested by beetles to the age of trees in the green stand, it was found that maturity is of little value as an added factor to ratings of risk to be used in predicting which trees are most likely to become attacked, but that the preponderance of risk trees occurs in the overmature age class. Other things being equal, age should be considered in the grouping of risk trees. By subdividing risk according to crown vigor classes, no additional refinement in rating risk was obtained.

The ratio of mortality, or the relative susceptibility of trees, was found to be greatest in the high risk classes in Keen's susceptible tree classes. It is concluded from the evidence shown in the comparisons made of risk mortalities that characters indicating crown deterioration are the primary factors denoting current health in trees and the likelihood of immediate future death. Any increase in the accuracy of predicting which trees are most likely to be attacked and killed by beetles seems to be dependent on weeding out the crown characters indicating but temporary disturbances in tree health from those of significance as indicators of high risk and susceptibility, or in discovering other conditions not presently recognized as indicators of high risk.

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